Overcoming the final frontier of climate change in viticulture: exploring interactions between society and environment using Agent-Based Modelling and Companion Modelling approaches

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Abstract

Climate change is a complex process that requires societies to seek viable adaptation solutions. Agent-based modelling using co-constructed models can thus be seen as a means of understanding the manner in which societies in wine-growing areas take into account the different variables that influence their systems. Here we offer a reflection on three years of companion modelling carried out in the AOC Banyuls-Collioure (Fr) and Val di Cembra (It). This work has led us to co-construct six agent-based models and to produce a future-oriented summary, enabling us to identify the macro-variables that influence these environments.

Keywords: agent-based model (ABM), companion modelling, systemic approach, stakeholders, landscape

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Introduction

Climate change is a complex process that highlights gaps in our ability to understand the underlying drivers. Most of the controversial gaps have an anthropogenic origin (Guillemot, 2014) and raise questions about societies' ability to adapt to climate change. These questions and solutions for adapting to climate change seem too complex, and the uncertainties too large, to be left to a formal, disciplinary scientific approach. Funtowicz and Ravetz (1993) suggest resorting to "post-normal" science. This involves tackling complex problems in an inter-disciplinary manner, including bringing in various stakeholders, in order to provide and integrate solutions into societies.

In this paper, after reviewing current work in agent-based modelling used in climate change context, we propose the use of multi-agent systems (MAS), adopting a companion modelling approach. The co-construction method was used on six models, in collaboration with stakeholders, in two wine-growing areas: the AOC Banyuls-Collioure (Fr) and Val di Cembra (It).

Each co-constructed/companion model leads to a partial understanding of the system. However, when these models are considered as a system, they allow us to outline stakeholders' perception abilities of these environments.

A short introduction to agent-based modelling

1. What is modelling?

The concept of modelling is part of the scientific approach. A model is a simplified representation that allows us to think the world based on hypotheses. Modelling is therefore an intellectual construction that i) involves interactions between a range of ideas and concepts, and ii) allows to put together reasoned arguments suitable for sharing (Le Page *et al.*, 2010).

Multi-agent modelling emerged in the 1980s from the crossover between computing (object-oriented programming, distributed systems, etc.) and distributed artificial intelligence (artificial life, robotics, cognitive sciences). Ferber (1995) stresses that the development of distributed artificial intelligence requires several conditions, including i) the need for a system to "*adapt itself to the modifications of its structure or its environment*" and ii) a "*complex problem that calls for a local perspective.*" An agent is defined as "*a physical or virtual entity that: a. can act in an environment, b. can communicate directly with other agents, c. is driven by a set of trends (in the form of individual objectives or functions that must be optimised), d. has its own resources, e. can perceive its environment, f. has only a partial vision of this environment, g. possesses skills and offers services, h. might be able to reproduce itself, and i. adopts behaviour in order to meet its objectives, taking into account the available resources and the perceived images and received information.*" (Ferber, 1995).

We are interested here in the use of modelling and multi-agent simulation in social sciences, in the same way they are used in experimental sciences, as a tool allowing us to access *in silico* (Knibbe, 2013) socio-spatial configurations that are difficult to tackle by conventional methods. By applying these models, social scientists can access the field of experimental scientists (Peschard, 2011) in the same way that biologists use the "Petri dish".

2. From system to model: theorising the world?

Systemic modelling has been developed in the middle of the 20th century, in a cross-disciplinary approach that broke away from reductionist modelling. This approach allows us to think complex objects as a whole. The systemic approach can be linked to various scientific disciplines having an ambition to theorise. For Pumain (2003, p. 27): "*To theorise is, first of all, to try to escape from the paradox of "pure science" and, above all, to look beyond the irreducible oneness of things, to try to construct a nomothetic view of the discipline.*"

Moving towards a systemic approach is therefore not neutral and involves going beyond the "tangible/real". This scientific position offers the possibility to grow in abstraction and think easily transferable theoretical generalisations.

In France, when looking at viticulture, we can single out the attempt of systemisation proposed by Auriac (1979). This work, using General System Theory (GST), offers a new approach to viticulture geography by theorising the "vineyard-system" as a dynamic object.

3. Roles and status of the model

This need to step back from "concrete" forms of the world became apparent during the 20th century and was a definitive turning point for scientific models. It raises questions about the emerging need for theorisation in all the scientific disciplines.

Researchers (as observers) must change their point of view and concentrate on the phenomena of form generators. Thom (2009) questions this observer role:

"*Can someone, in a landscape of phenomena, recognise an object if there is prior concept of it? It's as simple as that. If you don't have a concept of an object, you cannot recognise it. [...] The possibility of recognition of an entity in an empiric landscape is always subject to conceptualisation.*"

This link between conceptualisation/formalisation and the recognition of a pattern in the results requires proceeding from an iterative basis by confronting hypotheses with experimentation and then by rejecting or confirming these hypotheses.

4. Empiricism and ABM/MAS: an empty space for post-normal science

One of the challenges in social sciences has always been to move from the description of reality to the abstraction that leads to theorisation. At the same time, more and more interdisciplinary studies try to understand interactions and associated organisations rather than predict the state of a future system (Etienne, 2013). When the questions of research collide with great uncertainties and face major social issues, their resolution goes beyond the factual scope of science, leading to the paradigm of "post-normal" sciences (Funtowicz and Ravetz, 1993). The "post-normal" approach does not banish the uncertainties but seeks to overcome them by including the stakeholders (Funtowicz and Ravetz 1993, p. 740). The quality of the solution to the problem depends not only on scientific abstraction but also on the decision-making process (Etienne, 2013). The role of the scientist is thus redefined as a guide in this process. It reintroduces the legitimacy of an empirical approach.

However, empirical agent-based modelling approaches must translate the real world into a robust model. For Smajgl and Barreteau (2013), this translation is equivalent to bringing together a range of parameters from heterogeneous sources, with a range of valid results from observation and measurements. Moreover, agent-based modelling mobilises more complex information than the links between model inputs and outputs: "*It also provides information on the structure of the population of the target system so that up-scaling can be performed to generate a suitable artificial population. [...] Parameterisation is not only a matter of giving quantitative value to parameters, but also a matter of being able to run the model with a set of values. Sets of categories are particularly useful for qualitative or fuzzy approaches.*" (Smajgl and Barreteau, 2013, p. 3).

Climate change, land use adaptation and ABM

1. Climate change and adaptation

For over twenty years, IPCC has been working on long-term evolution of climate change, making populations aware of climate-related impacts that may arise. Climate change has become a key issue for viticulture (Nemani *et al.*, 2001; Jones *et al.*, 2005; White *et al.*, 2006; Schultz, 2010). At the same time, controversies have emerged regarding the future of viticulture (Hannah *et al.*, 2013 vs. Van Leeuwen *et al.*, 2013). Even though climate change itself is no longer disputed, the ability of wine-growers to take advantage of their environmental and cultural practices is now in question, as raised in the research program LACCAVE[1] (2012-2015) (Barbeau *et al.*, 2014; Ollat and Touzard, 2014; Viguié *et al.*, 2014; Neethling *et al.*, 2016).

2. Climate change and ABM

Investigating climate change issues through MAS leads to difficulties: i) the processes that influence climate change are not precisely understood and ii) no social theories are universally suitable in this context (Moss *et al.*, 2001). In general, the studies we identified on wine growing tend to address the society-environment link in economic terms.

The objective of these models is to offer to decision makers a theoretical framework that helps them to think about the effects of climate change. The "social" agents of the model are trying to maximise their revenues in a system facing several constraints. By trying to sum up the knowledge of the subject, the modellers have a dilemma about the degree of formality and the degree of abstraction of the models (Moss *et al.*, 2001; Banos and Sanders, 2013). Using the classification method suggested by Banos and Sanders (2013), we studied eight articles that tackle climate change in viticulture from a MAS perspective.

By placing each of these studies in a "horseshoe" grid (figure 1), we notice that none of them are in the A or B part of figure 1. This absence reveals science's lack of objectivity regarding climate change and the difficulties to raise the level of abstraction. Also, all these studies are based on particular viticulture areas and use formalism tending towards KIDS[2] (Edmonds and Moss, 2005).

[1]LACCAVE: Long-term impacts and Adaptations to Climate Change in Viticulture and Enology.
[2]KIDS, short for *Keep It Descriptive and Stupid*, is a modelling approach that seeks to describe interactions between agents as precisely as possible.

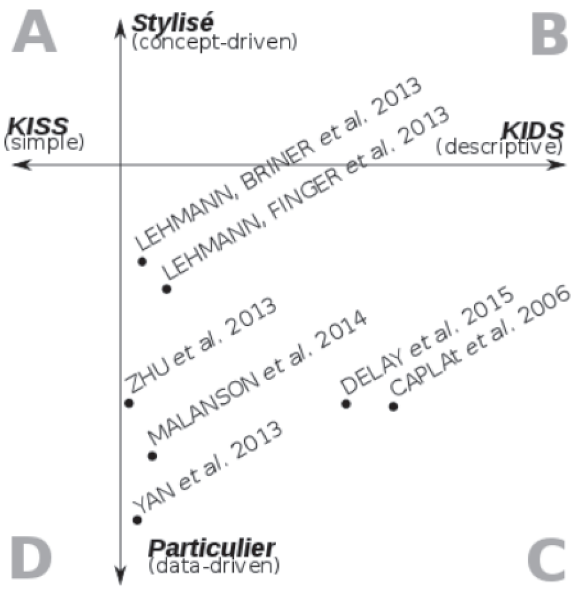

Figure 1. Placing the models in a "horseshoe" grid, as suggested by Banos and Sanders (2013).

This over-representation probably results from the need to base the models on a "target area", where the efficiency and robustness of the model are tested. This local dependency is generally due to the access to climate data and/or to the methods of gathering social information, focusing on understanding the dynamics of a focal point. After that it is hard to go from a quite descriptive model to a more abstract and concept-driven model.

Examples of the use of ABM in understanding complex local socio-systems subject to climate change constraints

The interdisciplinary nature of multi-agent modelling applied to viticulture under climate change led us to adopt a "post-normal" stance, involving all stakeholders in the modelling process (Funtowicz and Ravetz, 1993). Nevertheless, the range of problems to be addressed is so wide that implementing a co-construction with all of these actors and their points of view appeared impossible. To include multiple viewpoints and designs into an object covering many forms of reality (Watzlawick, 1976), we suggested an approach that combines several models controlled by the analysis of the constraints and uncertainties of their uses (Delay, 2015).

Thus, based on the work of Neumann (2015), we first constructed an ontology on the field of viticulture under climate change (Delay, 2015). Then we co-constructed, along with the stakeholders, six models, each responding to questions arising locally and corresponding to a limited part of the ontological domain, somewhat like a fragmented vision of the world. We will present them in pairs, and then we will show the relationship between them.

1. Large spatial scale: the pathway to abstraction

The first models are "Dion still alive" and VICTOR: two multi-agent models that simulate the viticulture area on a small scale with agents aggregated in the towns, villages and market places. These two models replace the steep slope viticulture in the "viticulture-system" by focusing our attention on the effects that orography has on the structuring and the dynamics of wine-growing areas. These two abstract models are based on theoretical data and knowledge. Their interest (for scientists and technicians) relies on the validation of relationships and processes necessary to generate the spatial dynamics observed in real life. Observable emergence enables us to hypothesise and explore the implications that theoretical parameter might have on space and time.

The "Dion still alive model" (Delay and Chevalier, 2015) proposes to revisit the hypotheses put forward by Dion (1952) in his article "Querelle des anciens et des modernes sur les facteurs de la qualité du vin" ("Quarrel between traditionalists and modernists about wine quality factors"). This work, apart from the reinterpretation of Dion with regard to simulation, also prompts us to reflect about formalism in the long-term evolution of quality. Here, the slope is a quality criteria much sought by the agents, influencing the global spatial dynamics.

The VICTOR model (Delay, Leturcq, and Rodier in press) explores the agricultural dynamics that arises in a wine-growing area when competition between two crops, vines and cereals, is introduced. This model is therefore used to simulate the effect of different types of market on local communities. Here we explored the effect of economic stimulation on the wine-growing area when it is in competition with subsistence farming. In this case, sloping land is considered as a poor environment, unfavourable for cereal production. It therefore represents a refuge space for viticulture even when economic conditions favour cereals.

2. Meso-scale: towards taking into account viticulture dynamics

Next we explore "individual-centred" models at greater spatial scales using the LAME (Delay *et al.* 2012) and CiVIsMe (Delay, Chevalier *et al.* 2015) models. These models attempt to formalise individuals' behaviours in a simplistic way, which, in a "principle of plausibility" (Varenne 2011), allow us to consider the spatial dynamics of the vineyard. The iterative construction of these models with local actors[3] ensures this "plausibility of principle" with the reality of the wine-growing area.

The LAME model explores the importance of environmental factors, such as slope and accessibility, taking into account how the winegrowers choose the place of plantation, reusing or abandoning their plots. This work is first carried out in an artificial environment, and then with real data.

The CiVIsMe model studies the ever-present cooperative effect found in many vineyards located in difficult geographical conditions. We use it to evaluate the implications of the grape payment rules in the cooperatives. This model also allows to identify the influence of land structure and thus to explain any local differences that might arise in cooperative behaviours.

3. Finer spatial scales and local dynamics: abstraction assists in considering local dynamics

In this last "downscaling" stage, we focused on very specific processes. Our objective was to respond to the particular needs of the stakeholders involved in our study. These winegrowers and technicians, who participated in the other modelling approaches by validating performance and discussing hypotheses and results, were especially interested in local models. We therefore submitted the next two models, acidityGIS (Delay, Piou, and Quenol, 2015) and CeLL (Delay and Caffarra, 2015), in response to their requests. These models integrate economic data, along with spatial temperature data, in order to assess the impact of spatial heterogeneity on the models' performance.

Considering the impacts of climate change at the Mediterranean basin scale like Hannah *et al.* (2013) does not consider all adaptation available at the small-scale level (van Leeuwen *et al.*, 2013). The wine-growing area of Côte Vermeille is at greater risk from climate change than other regions. The acidityGIS model, used in a cooperative context, explores the possibilities offered by orography to maintain grape ripening according to the specifications of the AOC[4] system.

The CeLL model aims to offer winegrowers food for thought about their pest (insect)-control methods. CeLL models the behaviour of a vine parasite known as Eudémis or European Grapevine moth (*Lobesia botrana*). This Lepidoptera, which lays its eggs under the skin of the grape, is particularly temperature-sensitive. By means of an "individual-centred" model, we simulate the behaviour of butterfly populations on a small scale in order to optimise pest-control strategies by the use of pheromone traps. The development of the CeLL model allows us to test *in silico* a certain number of variables and to show the potential results of different integrated pest management approaches.

The integration of MAS in a local prospective approach

Considering an area and climate change via several models has two advantages: i) it produces direct results on which the stakeholders can act and ii) it offers the researchers a set of models addressing the subject from different angles, each corresponding to the point of view of a particular group of actors. In the following section, we present the second advantage of this multi-model approach.[5]

1. Looking ahead using a system of variables built on models

For the researcher who wants to explore the future by using a set of models, the challenge is to build a meta-model that helps to "think ahead".[6]

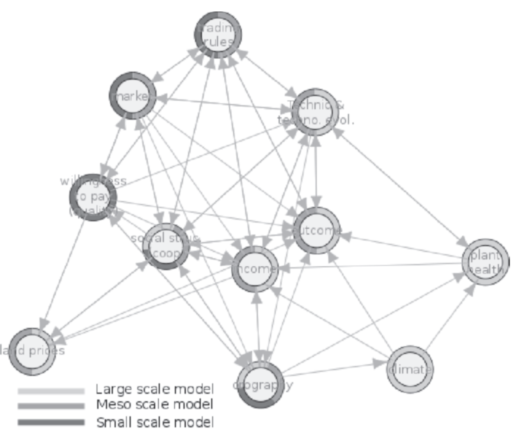

Figure 2. Diagram showing the interaction between structural macro-variables, in which we can observe the different spatial scales that apply to each variable.

[3]The actors in this case are technicians from local organisations, such as the chamber of agriculture, the winegrowers' syndicates, agricultural cooperatives, etc.

[4]Optimising the double ripening of berries: polyphenolic maturity and technological maturity.

[5]The contribution of the method, producing results that can be used by stakeholders, was described by Delay, Piou and Quenol (2015) and Delay and Caffarra (2015).

[6]We were inspired here by the work of Hannin *et al.* (2010, p. 227), who identified 50 traits specific to viticulture.

The MicMac method[7] put forward by Godet (1985) suggests the use of structural variables coupled with an approach based on graph theory in order to analyse interactions between different variables. We identified 11 macro-variables resulting in the clustering of several modelled processes.

The second stage of the method consists in studying the types of relationship between the variables, constructing a network of dependencies based on graph theory. Figure 2 shows the interactions between the macro-variables from the models co-constructed with the stakeholders. This graph therefore represents the systemic vision that the stakeholders developed, in other words, a synthesis of the abstraction that the stakeholders made via the modelling work we carried out with them.

The stakeholders from the Banyuls region verified this system of variables during a round table workshop.

This meeting brought to light a perception shared by the winegrowing community. We noticed the actors' underestimation of the importance of the community level and the predominance of the global context, to which they respond mainly at an individual level. This shows their difficulties in participating in the cooperative organisations, which represent the broad majority of actors in this area, as they refuse to question[8] their collective rules and attribute their difficulties to external forces.

Focusing on climate and climate change, we see that these issues are indeed present in the minds of the stakeholders but that the solutions for adaptation are found on a local scale. Individually and collectively, they feel that it is impossible to influence global dynamics. Nevertheless, local adaptation is possible (van Leeuwen *et al.*, 2013; Viguié *et al.*, 2014) by redistributing the space constraints and using orography to respond to these new constraints.

Conclusion

Agent-based models and complexity science are tools to help us consider the world in an integrated approach. These tools can be used as such to provide answers to social questions. The combined use of several models as prospective tools can offer a systemic approach to the projection issues met by the stakeholders.

The construction, or co-construction with the stakeholders, of models allows access to what Weber (1922) identifies as "causal adequacy". This corresponds to identifying consistent interactions from the point of view of the actors (empirical).

At the same time, "meaningful adequacy" (Weber, 1922), that is to say consistent with reality, is identified in the general discussion during the validation exercise. The "distance" between these two types of adequacy shown in the macro-variable systems helps us to understand how the stakeholders think about their area and their interactions. Thus, while the levers for adjustments and local dynamics can be partially put into motion by the stakeholders on an individual basis, a great number of variables, on a more global level (market, or trading rules, etc.), remains beyond their grasp.

The findings of these modelling-based studies demonstrate the need for quite specific local adaptations. A question remains regarding the flexibility of our system of variables. It will be interesting in the future to continue to explore configurations where orography is less important in order to i) evaluate the (longer term) durability of the variables in the systems and ii) identify other levers of local adaptation that could be transferable into different contexts.

[7]"Matrice d'Impacts Croisés - Multiplication appliquée à un Classement".

[8]At the same time, the actors regularly question the workings of the models. Two of the six models developed concern in particular the cooperative objective, while another explores the "cooperative factor" in insect pest control.

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Models	Question	Public	Space Scale	Time Scale	Entity
Dion still alive	What is the influence of an external market on the spatial structuration of vineyard areas?	Researchers	Regional abstract space	Year	Vine plot, local wine market, external wine market
ViCTOr	What happens spatially when vine plot is in competition with grain?	Researchers	Local community abstract space	Year	Vine plot, grain plot, village
LAME	How does steep slope influence spatial choices and spatial distribution of vine plot?	Researchers and technicians	Abstract steep slope space	Year	Vine plot, winegrowers
CiVIsMe	How do cooperation and cooperative influence the socio-spatial dynamics of steep slope vineyard plots?	Technicians	Abstract steep slope space	Year	Vine plot, winegrowers and cooperatives
AcidityGIS	How can cooperatives manage the vineyard in a climate change context?	Technicians and winegrowers	Banyuls-sur-Mer (Fr)	Year	Vine plot, winegrowers and cooperatives
CeLL	How can integrated pest management be optimised by better spatial organisation of pheromone diffuser in a small watershed?	Technicians and winegrowers	Banyuls-sur-Mer (Fr) and Cembra (It)	Day	*L. botrana*, vine plots and pheromone diffuser

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